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Dehydrated Mashed Potatoes— Potato Granules

W. F. Talburt
F. P. Boyle
C. E. Hendel

Dehydrated mashed potatoes are prepared in two forms—granules and flakes. The manufacture and properties of potato granules are discussed in this chapter. Potato flakes are discussed in Chapter 13.

Potato granules are dehydrated single cells or aggregates of cells of the potato tuber dried to about 6–7% moisture. The granules are made into mashed potatoes very readily by mixing with hot or boiling liquid. They are a convenience food that helps the potato industry maintain its position in the face of increasing competition from the many other convenience foods on the market. They are adapted for use both in the home and in restaurants and other group-feeding establishments. Potato granules can be reconstituted to a texture that is either dry and mealy, or moist and creamy, according to individual preference.

Potato granules were first introduced into the United States about 1948 as a product for home use; military interest in this product was greatly stimulated in the 1950s during the hostilities in Korea. Production statistics indicate steady growth from about 15 million lb of finished product in 1953 to an estimated 120–130 million pounds in 1966.

Since 1972 the production of potato granules in the United States has declined somewhat because of decreased purchases by the armed services. There is still substantial demand for dehydrated potato granules by institutional users and the consumer market. They are produced by a number of companies in the Washington–Idaho–Oregon area.

Factors accounting for the popularity of this product include not only convenience but also high quality and moderate cost. Cost is moderate because of the nature of the process used for manufacture and the high bulk density of potato granules, which results in minimum costs for packaging and of shipping.

The many investigations aimed at improving processes for manufacture of potato granules were reviewed by Olson and Harrington (1951, 1955A.B), Kueneman (1957), and Feustel *et al.* (1964). Since the mid-1970s, the process for the production of potato granules has seen no radical changes, although minor changes have been incorporated in the process. Reduction of temperature during conditioning of the moist mix and preheating of the raw material at temperatures below 100°C prior to final cooking and mash-mixing have been employed to improve quality and yields of the granules.

THE ADD-BACK PROCESS

Although a number of processes have been developed for the direct production of potato granules, none of them is in commercial use in the United States at the present time. In the standard commercial procedure, termed the *add-back* process, cooked potatoes are partially dried by adding back enough previously dried granules to give a *moist mix,* which after holding can be satisfactorily granulated to a fine powder. The procedure is outlined schematically in Fig. 12.1.

Following peeling and trimming, the potatoes are usually sliced (thickness ⅝ to ¾ in.) to promote uniformity of cooking. Cooking is in steam at atmospheric pressure, with the potatoes on a moving belt at a depth of about 6–8 in. Cooking time depends on the raw material and on the altitude, but is usually in the range of 30–40 min. Mashing and mixing with the dry add-back granules is then performed, and the resultant moist mix is cooled to approximately 15°–27°C. It is then conditioned by holding for about 1 hr at this temperature, mixed, dried in one or two stages to about 12–13% moisture content, and screened. Material coarser than about 60–80 mesh is returned to the process as add-back for succeeding cycles. A part of the fine material passing through the screen is also returned as add-back, but the part to be used as product of the cycle is further dried to a moisture content of about 6%. A small portion of very coarse material, retained on a screen of about 16-mesh size, is removed from the process because it does not absorb moisture from the cooked potatoes fast enough to be helpful.

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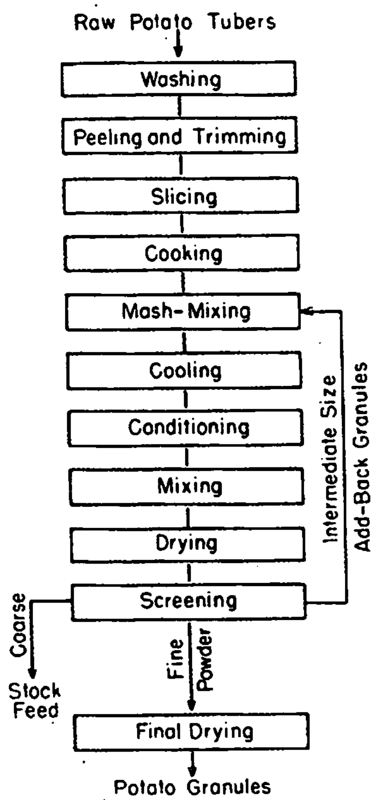

Fig. 12.1. Schematic outline of the add-back process for manufacture of potato granules.

About 12–15% of the material is removed as packout; the remainder is used as add-back.

The early workers who contributed to development of the add-back process included Bunimovitch and Faitelowitz (1936), Volpertas (1939, 1944), Rendle (1943, 1945), Bar (1943), and Rivoche (1948, 1950). Much improvement after 1950 resulted from efforts of the commercial manufacturers and of several research institutions including the Quartermaster Food and Container Institute for the Armed Forces. Developments of one commercial concern were reported by Kueneman and Havighorst (1955). An extensive potato granule research program was conducted at the Western Regional Research Laboratory during this period.

GRANULATION AND AVOIDANCE OF CELL RUPTURE

Essentials in manufacturing potato granules are (1) minimizing rupture of the potato cells and (2) satisfactory granulation. Rupture of cells releases free starch; the product becomes unduly sticky or pasty if this is excessive.

Satisfactory granulation is necessary to avoid graininess or lumpiness in the product from the add-back process. The packout granules should for the most part be unicellular; furthermore it is necessary that the add-back material contain a certain proportion of these fine granules. Poor granulation is self-perpetuating. If it begins, the proportion of large-size granules in the add-back will tend to increase progressively with continued recycling. The larger particles do not absorb moisture rapidly enough to lower the moisture content of the freshly cooked potatoes to such a point that granulation occurs readily. The proportion of large-size granules may become so high that alteration in the process—for example increasing the proportion of add-back to cooked potatoes—will be necessary to permit maintenance of packout particle size within established specifications and to avoid excessive quantities of very coarse material, which must be removed from the process.

Granulation is markedly improved by the holding (also called *conditioning* or *tempering*) of the moist mix. Olson *et al.* (1953) showed that granulation was improved by decreasing moisture content of the moist mix, which is usually about 45%, to 35%. Granulation also was improved by lowering the temperature of conditioning. Olson and Harrington (1955A) reported a 20% yield of smaller than 70-mesh product when the moist mix was tempered at 58°C compared with 62% smaller than 70 mesh for moist mix tempered at 4°C.

Potter (1954) showed that both in moist mixes and in potato starch gels there is a decrease in soluble starch during conditioning. Also, the swelling power of the moist mixes decreases during conditioning. The conditions causing fastest change in these properties of the starch were found to parallel those that improve granulation of the potato granules during conditioning. It was therefore concluded that changes in physical properties of starch play an important role during the conditioning or tempering period used in the manufacture of potato granules.

Figure 12.2 from the work of Potter (1954) shows that decrease in soluble starch during tempering of a moist mix at 28°C was most rapid

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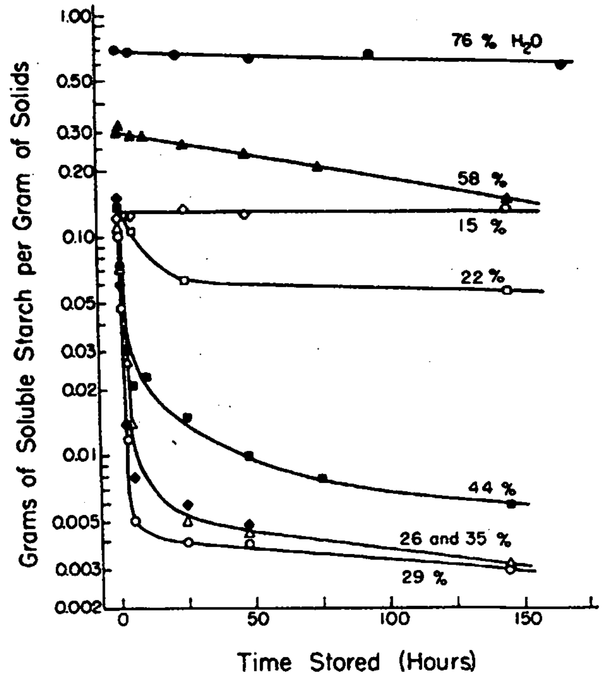

Fig. 12.2. Effect of moisture content of moist mix on retrogradation of starch. (From Potter 1954.)

at a moisture content of 29% and nearly as rapid at 26 and 35%, but that no change occurred at moisture contents of 15 and 76%. Fig. 12.3 shows the acceleration of change in free starch in a moist mix with decrease in temperature from 50° to 5°C.

The decrease in soluble starch (*retrogradation*) is considered due to an association of the starch molecules, probably by hydrogen bonding either directly or through molecules of water bridging between active sites on the starch molecules.

An excellent review article on the interrelationship between starch and pectins as factors in different textural qualities of potatoes was published by Reeve (1977). This review includes examples of texture control through processing treatments. The role of pectins in effecting these textural changes and in cell separation is explained. Previously unpublished observations on cell sloughing and cell separation are included. A number of microphotographs that illustrate factors involved in cell separation during heating of potato tissue are included.

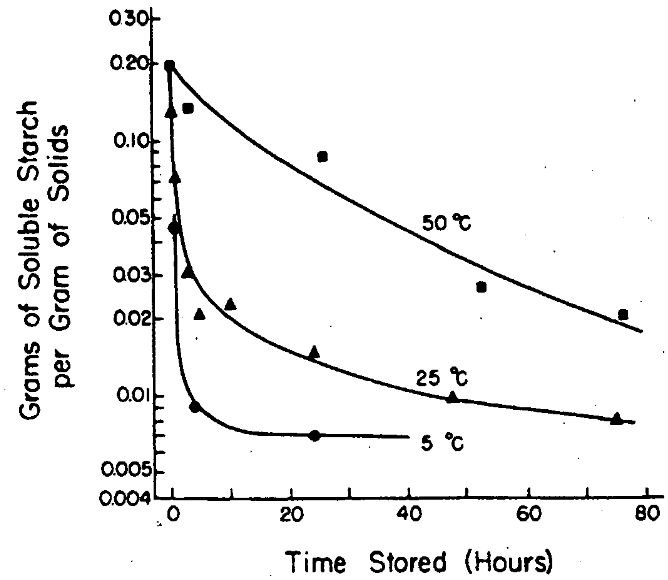

Fig. 12.3. Effect of storage temperature on retrogradation of starch in a moist mix. (From Potter 1954.)

This article points out the problems of obtaining adequate cell separation during the manufacture of potato granules and provides clues for improving product quality and increasing yields.

Ooraikul (1978) reported the results of a rather extensive experimental procedure for producing potato granules using the freeze-thaw process. This process involves the freezing and thawing of cooked mashed potatoes followed by drying under precisely controlled conditions as to time and temperature.

Moledina *et al.* (1978) used scanning electron microscopy to study microscopic changes in the surface structure of potato cells resulting from the add-back process for granule production. These results were compared with those obtained from the experimental freeze-thaw process for granule production described by Ooraikul (1978). In these studies it was found that potato cells appeared to be more prone to damage in mash-mixing during the add-back progress than in freeze-thaw granulation. Add-back particles were largely round and compact with smooth surfaces; freeze-thaw granules were mostly angular and covered with minute holes. These holes were said to permit more rapid rehydration. The oversize material from the add-back process, which consisted of clusters of cells that had not separated during granulation

or agglomerates formed during mash-mixing, could amount to 5% of the total product.

MANUFACTURING OPERATIONS

To minimize cell rupture and resultant release of free starch, all manufacturing operations are carried out as gently as possible. Mashing is now usually by the mash-mixing technique in which hot cooked potatoes are mixed with dry add-back granules until an apparently homogeneous moist mix is obtained (Harrington *et al.* 1958). Indications are that the repeated mild shearing and pressing action of the dry and partially dry granules against the cooked potato tissue causes separation of the latter into individual cells with fewer broken cells than when mashing is carried out by other means, for example by extrusion or on mashing rolls.

Cooling of the moist mix is effected gently in a shaker–cooler in which the product is passed over a vibrating screen of very fine mesh, through which cool air is passing.

In present practice, conditiong of the cooled moist mix is usually on moving rubber belts approximately 4 ft in width and depressed at the middle to form a wide V. Depth of product at the center of these belts is only about 6–9 in. It is thus possible to avoid excessive compression (which results in some agglomeration) and the mechanical damage from auger screws, which occurs when deep beds are used for conditioning.

Since some agglomeration does occur during conditioning, a gentle mixing is often employed at the end of the conditioning period. A scalping reel is frequently included at this point to remove any very large agglomerates and any bruised portions of potato tissue that were not removed during the trimming. Regions of the potato that were bruised during harvesting or handling may undergo discoloration during storage of the fresh potatoes. Removal of all of these discolored regions by trimming is both difficult and expensive. It is an advantage of the add-back process that these discolored regions are relatively hard and do not break up during mash-mixing. Hence they can be removed by scalping following the conditioning. This feature of the add-back process makes for both better quality of product and lower cost of production than is possible with other methods of manufacture.

The product then goes to the driers, where again every effort is made to minimize cell damage. Several kinds of driers are in use. The product is usually airborne while dried, thus avoiding agglomeration that

would occur if the particles were in contact with one another during drying, for example as in tray drying. The principle of avoiding abrasive damage during drying is illustrated in the air-lift drier in Fig. 12.4. The drier consists of a vertical tube with upward flow of hot air. The moist feed enters at the bottom. Drying occurs as the product is rising in the tube and in the inverted cone diffuser at the upper end of the tube. The particles tend to remain suspended in the riser and in the diffuser until they have dried to such a point that their weight is low enough for them to be swept over the top of the diffuser into the collector. The air-lift drier operates at relatively low air velocities (1500–2000 ft/min), with minimum damage to the potato cells.

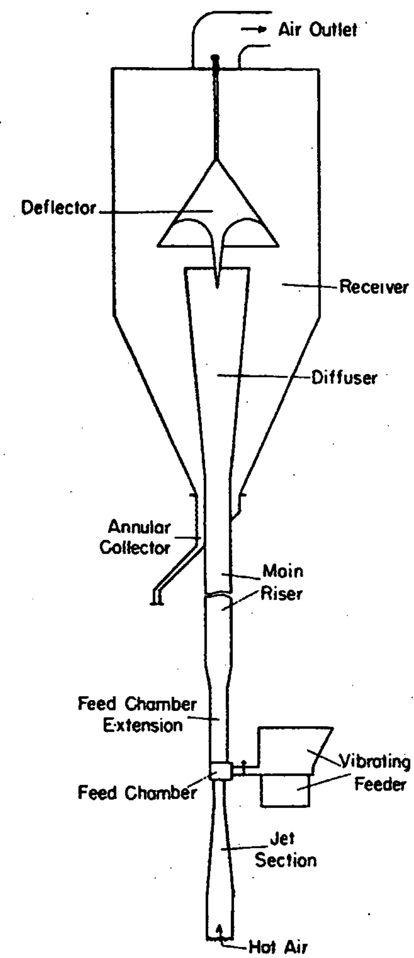

Fig. 12.4. Schematic diagram of air-lift drier used for drying of potato granules. (From Olson *et al.* 1953.)

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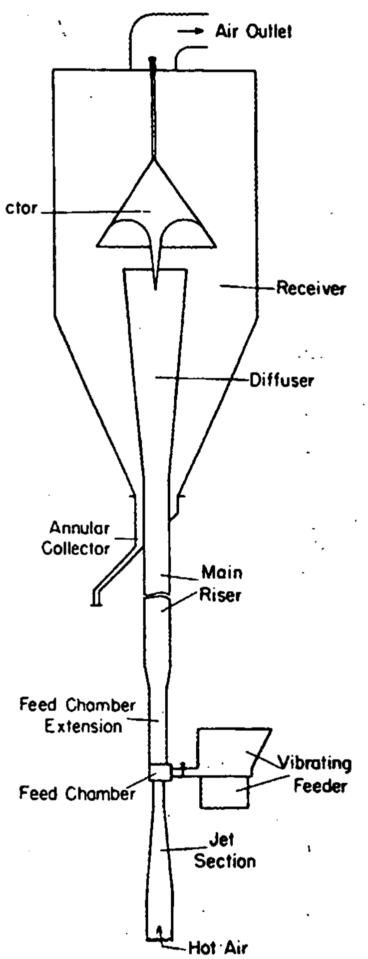

Damage can occur in pneumatic driers, especially with higher air velocities. Cooley *et al.* (1954) at the University of North Dakota demonstrated that damage occurred in both vertical and horizontal duct driers of 8-in. diameter at air velocities of 70 and 73 ft/sec (4200 and 4400 ft/min).

Following drying to about 12–13% moisture, the product is screened. The final drying of the packout granules, or product of the cycle, is carried out in a fluidized-bed drier, shown schematically in Fig. 12.5. This drier, developed at the Western Regional Research Laboratory, consists of a chamber with a porous ceramic or very fine mesh screen bottom through which heated air flows. The granules, entering continuously at one end of the drier and leaving at the other, are suspended or fluidized by the air from the porous bottom of the bed. The appearance of product within this drier is illustrated in Fig. 12.6. The granules offer no resistance whatever to lateral movement, flowing like a liquid. Drying occurs during the 10- to 30-min residence time. The inlet air temperature can be quite high without scorching the product because transfer of heat occurs so rapidly that none of the granules is exposed to a very high temperature. Typical relationships between feed rate, residence time, temperatures, and product moisture content are shown in Table 12.1.

Augustin *et al.* (1974) made a comprehensive study of several commercial dehydration plants to determine the direct effects of dehydration, under the conditions employed, on the protein and vitamin reten-

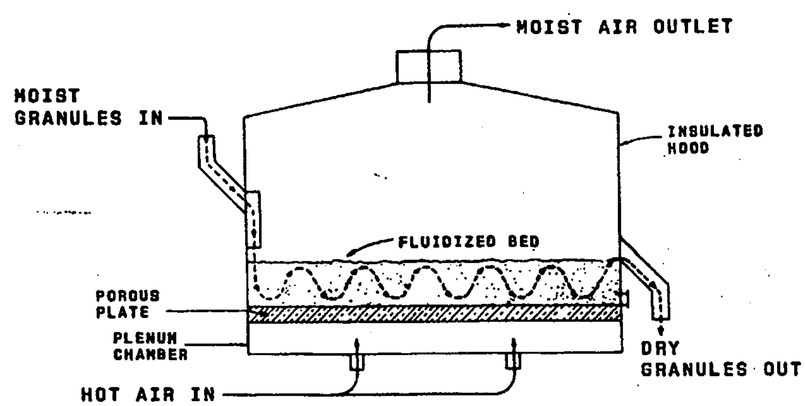

Fig. 12.5. Continuous fluidized-bed drier for use in finish drying of potato granules. (From Neel *et al.* 1954.)

Fig. 12.6. Fluidization of potato granules in fluidized-bed drier. (Courtesy J. R. Simplot Co.)

Table 12.1. Temperature, Residence Time, and Moisture Content Relations in Continuous Fluidized-Bed Drier

Feed rate (lb/hr/ft² of bed)	Residence time of granules in bed (min)	Temperatures (°F) Inlet air	Exhaust air[b]	Within the bed[b,c]	Product	Moisture content of product[a] %, wet basis)
18.0	28	300	114,136	139,151	142	5.0
30.0	17	400	118,143	141,162	150	5.0
18.0	28	400	136,162	172,192	174	3.0

Source: Neel *et al.* (1954).
[a] Moisture content of feed, 11.0%.
[b] Measured respectively 2 in. downstream from inlet, and 2 in. upstream from outlet.
[c] Measured with thermocouples, ¾-in. above the porous-plate bottom of the fluidized-bed drier.

tion of various potato products. Protein and vitamins, in general, were destroyed at those points where the potatoes were subjected to the highest temperatures for the greatest periods of time. Ascorbic acid, thiamin, niacin, folic acid, and vitamin B_6, in addition to protein, were evaluated in the study. Dehydrated slices and dice showed the lowest retention values of all the dehydrated products investigated.

STORAGE

Potato granules are subject to two principal types of deterioration during storage: nonenzymatic browning and oxidative deterioration.

Nonenzymatic Browning

Nonenzymatic browning has been widely experienced in dehydrated potatoes in dice form, and measures for control of it in potato granules are the same as those for dice, namely use of potatoes of low browning tendency, sulfiting, drying the product to low moisture content, and avoiding high storage temperature.

Nonenzymatic browning has a very high temperature coefficient, and the rate is exponential with temperature, following approximately the Arrhenius relation (Legault *et al.* 1947, 1951; Hendel *et al.* 1955A). With *each* increase in temperature of 10°C, the rate increases about five- to sevenfold, depending on the moisture content and the temperature. Taking sixfold as an average value, the rate increases about $6 \times 6 = 36$-fold with a temperature increase of 20°C and about $6 \times 6 \times 6 = 216$-fold with an increase of 30°C. Lowering the storage temperature is thus potentially by far the most effective method of controlling nonenzymatic browning. Often control of temperature is not feasible, but a combination of the other protective measures can usually provide satisfactory protection against browning.

Use of potatoes with a low content of reducing sugars is one of the best control measures since scorching during drying is also reduced. Nonenzymatic browning is approximately proportional to the content of reducing sugars, although exceptions to this general rule do occur. Potatoes with less than 1% of reducing sugars on a dry basis are best for manufacture of potato granules, but through much of the year the reducing sugar content of the available potatoes is much higher—2, 3, or even 4%. The problem is that in order to hold the fresh potatoes without undue sprouting, they must be stored at temperatures of about 5°C or lower, depending on the length of time the potatoes are to

be held. At 1.1° or 3.3°C potatoes in Idaho can often be kept from harvest in September or October until the end of the following June or even longer. At these low temperatures, however, there is a large increase in the reducing sugar content of the potatoes. Some reduction in sugar content can be obtained by holding the stored potatoes for 1–2 weeks at about 21°C before processing, but this conditioning treatment is only partially effective. A more promising procedure is to avoid storing potatoes below about 10°C, which is feasible when using sprout inhibitors such as maleic hydrazide (MH-40 or MH-30), methyl ester of naphthalene acetic acid (MENA), or isopropyl *N*-(3-chlorophenyl) carbamate (CIPC, or Chloro IPC). Problems remain to be solved in developing methods of using these inhibitors that will be most effective, least expensive, and that will not result in greater spoilage, but there seems little doubt that certain inhibitors will be widely used in the future for maintenance of processing quality in potatoes for the potato granule industry. Additional information on sprout inhibition is presented in Chapter 6.

Sulfite is effective in retarding browning. Precise quantitative data are not available for potato granules, but the amount needed for a given degree of protection is presumably similar to that in the case of dehydrated potato dice. From data available for dice (Legault *et al.* 1951; Hendel *et al.* 1955B) and on the basis of commercial experience in the manufacture and distribution of potato granules, it appears that with presently available raw material, sulfite at a level of about 200 ppm is necessary in potato granules to be distributed within the continental United States if they are to have satisfactory resistance to nonenzymatic browning in the period before they reach the consumer.

Sulfite is also effective in retarding scorching during drying and in addition helps reduce a graying that sometimes occurs during processing. This graying may be the same as the after-cooking darkening of potatoes. The chemistry of after-cooking darkening was reviewed by Saith (1957). He reported that sulfite is quite effective in reducing this darkening.

The fourth method of reducing browning of potato granules during storage is to lower the moisture content. The effect of moisture content on browning of potato granules during storage at 38°C is indicated in Fig. 12.7. Although lowering the moisture content and avoiding high temperature of storage are effective against browning of the finished product during storage, these procedures, of course, play no part in controlling scorching during drying, as do sulfiting and use of potatoes of low sugar content.

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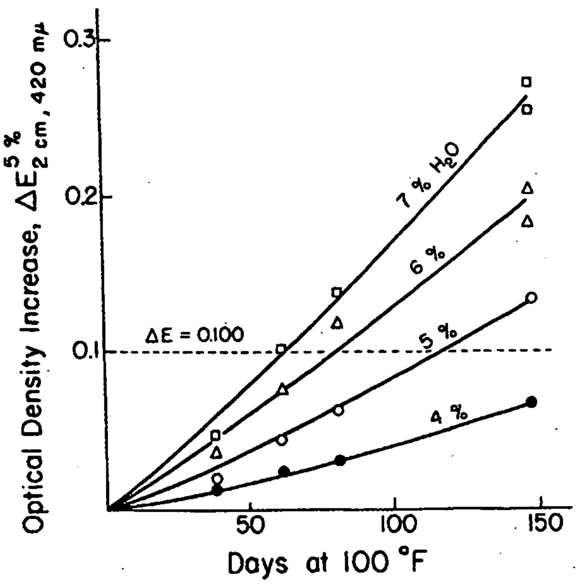

Fig. 12.7. Effect of moisture content on nonexymatic browning of potato granules during storage at 38°C. (Courtesy C. E. Hendel, H. K. Burr, and E. Wood.)

Oxidative Deterioration

Oxidative deterioration differs from nonenzymatic browning in several respects. The rate of oxidative change is not markedly affected by temperature of storage. Burton (1949) estimated that the rate is increased only about 1.2 to 1.4 times with a temperature rise of 10°C. Packing in nitrogen greatly retards oxidative deterioration, but it has little effect on rate of browning. Most strikingly, although lowering the moisture content *slows down* nonenzymatic browning, it *accelerates* oxidative deterioration. (Burton 1949; Hendel *et al.* 1951).

Nitrogen packing is used commercially for control of oxidative deterioration. Most of the oxidation is prevented, but a small amount occurs presumably because of the small percentage of residual oxygen that is usually present. The atmosphere of the package usually contains about 0.5–1.5% oxygen. When pin holes occur in foil laminate heat-sealed bags usually used for retail distribution, oxidative deterioration may be severe. Nitrogen packing is of no further benefit after the container has been opened.

Although packaging in an inert atmosphere is quite effective in preventing oxidative deterioration, packaging and material costs are

so high that other methods of preventing oxidative changes in potato granules are needed. Considerable attention has been given to use of antioxidants to control oxidation. A patent granted to Campbell and Coppinger (1955) of the Western Regional Research Laboratory specified three processes of stabilizing dehyrated vegetables: (1) treatment of the product with antioxidant before drying, (2) enclosing the dehydrated product in a sealed container together with a pad containing a volatile fat-stabilizing antioxidant, and (3) mixing the dried product with an edible dry component containing a volatile antioxidant and placing it in a sealed container. Butylated hydroxyanisole (BHA), either alone or in combination with propyl gallate and citric acid, and numerous other antioxidants have sufficient volatility to permit distribution throughout the dried material by diffusion in the vapor phase. Antioxidant levels of 0.1–0.001% (1000 down to 10 ppm) were preferred.

In extension of this work at the same laboratory, it was found that some people are able to detect BHA in potato granules at levels of 10 ppm (dry basis) and even lower. The sensation has been described as bitter, medicinal, and astringent. At low levels there is often a delay of 15–60 sec before the BHA is detected. Other antioxidants can similarly be detected at low levels. Oxidation can be inhibited at levels down to 1 ppm, but effectiveness is reduced at levels of ⅓ ppm. A desirable range for use of BHA appears to be about 1–5 ppm. In trials, butylated hydroxytoluene (BHT) seemed a little more effective than BHA. In case BHA and BHT act on different constituents in the potato granules, a desirable treatment might be 2.5 ppm of each of these two antioxidants. A convenient and effective procedure for addition of the antioxidants to potato granules is to intimately incorporate them with enough granules to give a concentrated mix containing 5000 ppm of antioxidant, and then to add enough of this concentrated mixture to the main lot of granules to give the desired level of antioxidant.

Stephenson *et al.* (1958) also found BHA quite helpful in retarding oxidation in potato granules, especially when used in conjunction with nitrogen-packing.

From the foregoing it might be assumed that effects of antioxidants are well understood, and that present methods of using them are entirely adequate. This is not the case, and in fact development of improved and less expensive methods of controlling oxidative deterioration is one of the most important needs of the potato granule industry. As used this far, antioxidants have been more effective against oxidative odor than against oxidative flavor. A possible explanation may

be that more than one type of constituent contributes to oxidative deterioration, and that constituents with volatile oxidation products are affected to a greater degree by the antioxidants than are those with nonvolatile products.

A comprehensive fundamental investigation is needed to determine the constituents of the potato that contribute to oxidative deterioration. There is evidence that the fats present in the potato contribute (Burton 1949; Hendel *et al.* 1951), but indications are that they cannot account for all of the oxidation. It is suspected, for example, that carotenoids may be among other constituents that are involved. Knowledge of the causal factors is urgently needed as a basis for technological investigations aimed at solution of the problems. The ultimate solution may result from selecting more suitable raw material, developing new antioxidants or new methods of using them that are tailored to the product, and/or developing new processing procedures (possibly granules without add-back) that will yield a product with less susceptibility to oxidative deterioration.

QUALITY EVALUATION AND ANALYTICAL PROCEDURES

As with other products, subjective appraisal is the ultimate basis for evaluating quality of potato granules, and this method is the only one available for evaluation of flavor and odor.

Objective procedures have proven useful for measurement of color, both natural color of the potato granules and that produced by nonenzymatic browning. Reflectance photometry has been used by Stephenson *et al.* (1958) and by W. O. Harrington and coworkers (unpublished). Soluble color procedures have been used to measure nonenzymatic browning, soluble colored constituents being extracted in various solutions, for example, 10% sodium chloride solution (Stephenson *et al.* 1958) or 55% ethanol solution (Hendel *et al.* 1950). Concentration of soluble colored constituents, which increases with heat damage, is measured photometrically.

Glass standards for visual color appraisal of potato granules were developed by Nutting *et al.* (1958). Beads of glass comparable in size to individual potato granules are admixed with appropriate pigments to give three stable color standards, designated respectively as good, borderline, and poor color. These standards are in jars. The granules are placed in similar jars that are placed in an illuminator for comparison

with the glass color standards. All of these color procedures are in need of refinement, as the results do not always correlate well with the color of the reconstituted granules.

Much attention has been given to developing methods of evaluating texture. Wood *et al.* (1955) described a subjective method of appraisal in which test samples are compared against two reference samples of potato granules differing in degree of rubberiness. The "high" control was less rubbery than the "low" control. Five categories of rubberiness were possible in the ranking system that was specified: A—less rubbery than high control; B—like high control; C—between high and low control; D—like low control;and E—more rubbery than low control. Use of reference samples, as in this method, is helpful in reducing uncertainty due to day-to-day and month-to-month drift in judges' memory, and in reducing the number of comparisons that must be made when large numbers of samples are to be intercompared.

Microscopic count of the number of broken cells has been used by a number of investigators to evaluate texture of potato granules from processes not involving add-back (Proctor and Sluder 1944; Campbell *et al.* 1945; Greene *et al.* 1947, 1948, 1949; Hall 1953). Within limits, the general textural quality of the reconstituted product could be predicted. With granules from the add-back process, Reeve and Notter (1959) and Reeve (1963) reported success with microscopic counts of ruptured cells and one estimating extra-cellular starch.

Harrington *et al.* (1960), Potter *et al.* (1959), Reeve (1954A,B), Zaehringer and Le Tourneau (1962), and Le Tourneau *et al.* (1962) have made studies on texture that permit objective and reproducible measurement of this quality factor. Cooley *et al.* (1954) reported successful use of a viscometer with reconstituted potato granules, although it was necessary to rehydrate the granules with appreciably more water than would be used for food preparation.

The Blue Value Index of Mullins *et al.* (1955) is easy to use and has proved helpful in process development, correlating well with texture if there are no large differences in procedure or in raw material. An extract of the granules is treated with iodine solution. The intensity of the resultant starch–iodine blue color, measured colorimetrically, is an index of the free starch that is present. However, the Blue Value Index is a measure primarily of the quantity of straight-chain amylose, and not of the branched amylopecin, which is present in larger quantity than is the amylose. Perhaps for this reason this Index has not proved a very reliable method for comparing texture of granules produced by different manufacturers.

A more direct approach, also proposed by Mullins *et al.* (1957), is the

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drop-test. Potato granules are reconstituted under standardized conditions and a round ball of the material is dropped from a fixed height. The diameter of the cake that is formed on impact with a solid surface is a measure of the consistency of the product, the larger the diameter the more mealy the granules. The diameter has correlated well with subjective appraisal of granules from different sources, as is shown by the data in Table 12.2, which also includes Blue Values for comparison.

Measure of sulfite content of the potato granules is necessary for production control and for purchase specifications of the armed forces and of commercial buyers. The Thompson and Toy (1945) modification of the Monier–Williams distillation method is very reliable, but it is time-consuming. It is the method required in U. S. military specifications (Anon. 1950). A rapid but less accurate method is the formaldehyde titration procedure of Potter and Hendel (1951). It is in rather common use, and is usually quite satisfactory, but if there is uncertainty it should be checked against the Thompson and Toy distillation procedure.

Measure of moisture content is another essential. The 6-hr vacuum oven method specified by the U.S. military (Anon. 1950) is commonly used both for control and as a reference method, although the Karl Fischer procedure (Johnson 1945) and the 40-hour vacuum oven method (Makower *et al.* 1946) are believed more accurate. The toluene distillation method is often used for production control.

Sugar content is usually measured in quality control laboratories by the dinitrophenol method if a colorimeter is available, or by the picric acid procedure if one is not (Ross *et al.* 1946). These methods give high results because of the presence of reducing substances other than sug-

Table 12.2. Comparison of Sensory and Objective Measures of Consistency of Potato Granules

Sample no.	Blue Value Index	Texture rank[b]	Mean cake diameter (mm)
1	35	1.1	71.4
2	133	2.5	65.5
3[a]	139	2.8	60.8
4	77	3.9	58.3
5	103	4.8	56.0
6	149	5.9	52.7

Source: Mullins *et al.* (1957).
[a] A laboratory sample. The other samples were from various commercial sources.
[b] 1 = least rubbery; 6 = most rubbery. Shortest significant range (Duncan) at $p = 0.05$ is 0.31.

ars, but they are rapid and relatively easy to use. In research laboratories it is sometimes feasible to employ methods that remove the nonsugar reducing substances. At the Western Regional Research Laboratory, an ion-exchange clarification procedure is used for removal of such substances (Williams *et al.* 1953; AOAC 1955), followed by measure of the sugars by the Somogyi copper method (AOAC 1955).

SUMMARY

Continued growth of the potato granule industry is anticipated. Product quality is good, and cost is low, the latter resulting in large part from the moderate costs of packaging and shipping this high-density product.

Nevertheless, improvements are needed, especially in storage stability, if the industry is to develop to the level that is possible. Even very minor differences in quality of this bland product will be important in determining the level of consumption that is ultimately reached.

Fundamental research is especially needed. We must greatly increase our knowledge concerning the constituents of potatoes and the changes that can take place in these constituents during processing and subsequent storage. The results of such fundamental investigations will serve as a sound basis for continued technological developments—for potato granules and also for other potato products—and will help assure that potato granules will be of greatest possible value as an outlet for potatoes in the markets of the future.

BIBLIOGRAPHY

ANON. 1950. Potatoes, White, Dehydrated. U.S. Military Specifications. MIL-P-1073A.

AOAC. 1955. Official Methods of Analysis of the AOAC, 8th ed. Assoc. of Official Analytical Chemists, Washington, DC.

AUGUSTIN, J., SWANSON, B. G., POMETTO, S. F., TIETZEL, C., ARTZ, W. E., and HUANG, C. P. 1979. Dehydrated potato products during commercial processing. J. Food Sci. *44,* 216–219.

BAR, P. J. 1943. Dehydrated potato product and method of making same. Brit. Pat. 566,498.

BOGGS, M. M., BUTTERY, R. G., VENSTROM, D. W., and BELOTE, M. L. 1964. Relation of hexanol in vapor above stored potato granules to subjective flavor estimates. J. Food Sci. *29,* 487–489.

BUNIMOVITCH, M., and FAITELOWITZ, A. 1936. An improved method of reducing

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AOAC, 8th ed. Assoc. of Official

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W., and BELOTE, M. L. 1964.
ıto granules to subjective flavor

An improved method of reducing

potatoes and other starch-containing vegetables to the form of a dry powder. Brit. Pat. 457,088.

BURTON, W. G. 1949. Mashed potato powder. IV. Deterioration due to oxidative changes. J. Soc. Chem. Ind. *68*, 149–151.

BUTTERY, R. G. 1961. Autoxidation of potato granules. Part II. Formation of carbonyls and hydrocarbons. Agr. Food Chem. *9*, 248–252.

BUTTERY, R. G., and STUCKEY, B. M. 1961. Determination of butylated hydroxyanisole and butylated hydroxytoluene in potato granules by gas-liquid chromatography. Agr. Food Chem. *9*, 283–285.

BUTTERY, R. G., and TERANISHI, R. 1961. Gas-liquid chromatography of aroma of vegetables and fruit. Anal. Chem. *33*, 1439–1441.

BUTTERY, R. G., and TERANISHI, R. 1963. Measurement of fat autoxidation and browning aldehydes in food vapors by direct vapor injection gas-liquid chromatography. Agr. Food Chem. *11*, 504–507.

BUTTERY, R. G., HENDEL, C. E., and BOGGS, M. M. 1961. Autoxidation of potato granules. Part I. Changes in fatty acids. Agr. Food Chem. *9*, 245–248.

CAMPBELL, T. W., and COPPINGER, G. M. 1955. Stabilization of dehydrated vegetables. U.S. Pat. 2,709,657.

CAMPBELL, W. L., PROCTOR, B. E., and SLUDER, J. C. 1945. Dehydration of precooked white potatoes in granular form. Research Reports on Quartermaster Contract Projects, Massachusetts Institute of Technology, July 1, 1944 to June 30, 1945, pp. 248–273.

COOLEY, A. M., SEVERSON, D. E., PEIGHTAL, D. E., and WAGNER, J. R. 1954. Studies on dehydrated potato granules. Food Technol. *8*, 263–269.

CORDING, J., JR., WILLARD, M. J., JR., ESKEW, R. K., EDWARDS, P. W., and SULLIVAN, J. F. 1955. Potato flakes, a new form of dehydrated mashed potatoes. II. Some factors influencing texture. U.S. Dept. Agr., Agr. Res. Sev. *ARS 73-9*.

FEUSTEL, I. C., HENDEL, C. E., and JUILLY, M. E. 1964. Potatoes. *In* Food Dehydration—Vol. II: Processes and Products. AVI Publishing Co., Westport, Conn.

GREENE, J. W., MARBURGER, G. C., and ROHRMAN, F. A. 1947. Instant mashed potatoes from dehydrated granules. Food Inds. *19*, 1622–1625, 1749–1751.

GREENE, J. W., ROHRMAN, F. A., MARBURGER, G. C., HONSTEAD, W. H., MESSENHEIMER, A. E., and OLSON, B. E. 1948. Development of a potato granule process. Chem. Eng. Progr. *44*, 547–552.

GREENE, J. W., CONRAD, R. M., and ROHRMAN, F. A. 1949. Dehydration process for starch vegetables, fruits and the like. U.S. Pat. 2,490,431.

GUADAGNI, D. G., BUTTERY, R. G., and OKANO, S. 1963. Odour thresholds of some organic compounds associated with food flavors. J. Sci. Food Agr. *14*, 761–765.

GUMBMANN, M. R., and BURR, H. K. 1964. Volatile sulfur compounds in potatoes. Agr. Food Chem. *12*, 404–408.

HADZIYEV, D., and STEELE, L. 1979. Dehydrated mashed potatoes—chemical and biochemical aspects. Adv. Food Res. *25*, 55–136.

HALL, R. C. 1953. Better potato dehydrating by slow freezing. Food Eng. *25*(3) 90–91, 150, 152.

HARRINGTON, W. O., OLSON, R. L., WESTON, W. J., and BELOTE, M. L. 1959. Effects of process variables in potato granule production. Am. Potato J. *36*, 241–254.

HARRINGTON, W. O., OLSON, R. L., and NUTTING, M. D. 1960. Effects of glycerol monostearate on reconstituted potato granules. Am. Potato J. *37*, 160–165.

HENDEL, C. E., BAILEY, G. F., and TAYLOR, D. H. 1950. Measurement of non-enzymatic browning of dehydrated vegetables during storage. Food Technol. *4,* 344–347.

HENDEL, C. E., BURR, H. K., and BOGGS, M. M. 1951. Factors affecting storage stability of potato granules. U. S. Dept. Agr., Western Regional Research Laboratory, Albany, California *AIC-303.*

HENDEL, C. E., BURR, H. K., and BOGGS, M. M. 1955A. Non-enzymatic browning and sulfite flavor in dehydrated white potato. Effects of sulfite level and method of sulfite application. Food Technol. *9,* 627–629.

HENDEL, C. E., SILVEIRA, V. G., and HARRINGTON, W. O. 1955B. Rates of non-enzymatic browning of white potato during dehydration. Food Technol. *9,* 433–438.

JOHNSON, C. M. 1945. Determination of water in dry food materials. Application of the Fischer volumetric method. Ind. Eng. Chem., Anal. Ed. *17,* 312–316.

KUENEMAN, R. W. 1957. Dehydrated mashed potatoes. Proc. Potato Utiliz. Conf. *8,* 64–70.

KUENEMAN, R. W., and HAVIGHORST, C. R. 1955. How to unit-engineer a line operation. Food Eng. *27*(5) 86–89, 212–213.

LAZAR, M. E., NOTTER, G. K., SMITH, G. S., REEVE, R. M., HENDEL, C. E., and MORGAN, A. I. 1964. The WRRL direct process for potato granules. Food Technol. *18,* 109–111.

LEGAULT, R. R., TALBURT, W. F., MYLNE, A. M., and BRYAN, L. A. 1947. Browning of dehydrated vegetables during storage. Ind. Eng. Chem. *39,* 1294–1299.

LEGAULT, R. R., HENDEL, C. E., TALBURT, W. F., and POOL, M. F. 1951. Browning of dehydrated sulfited vegetables during storage. Food Technol. *5,* 417–423.

LE TOURNEAU, D., ZAEHRINGER, M. V., and POTTER, A. L. 1962. Textural quality of potatoes. II. An objective method for evaluating texture. Food Technol. *16,* 135–138.

MAKOWER, B., CHASTAIN, S. M., and NIELSEN, E. 1946. Moisture determination in dehydrated vegetables. Vacuum oven method. Ind. Eng. Chem. *38,* 725–731.

MOLEDINA, K. H., FEDEC, P., HADZIYEV, D., and OORAIKUL, B. 1978. Ultrastructural changes in potatoes during potato granule process as viewed by SEM. Starke *30*(6) 191–192.

MULLINS, W. R., HARRINGTON, W. O., OLSON, R. L., WOOD, E. R., and NUTTING, M. D. 1955. Estimation of free starch in potato granules and its relation to consistency of reconstituted product. Food Technol. *9,* 393–395.

MULLINS, W. R., POTTER, A. L., WOOD, E. R., HARRINGTON, W. O., and OLSON, R. L. 1957. A physical test for consistency of potato granules. Food Technol. *11,* 509–511.

NEEL, G. H., SMITH, G. S., COLE, M. W., OLSON, R. L., HARRINGTON, W. O., and MULLINS, W. R. 1954. Drying problems in the add-back process for production of potato granules. Food Technol. *8,* 230–234.

OLSON, R. L., and HARRINGTON, W. O. 1951. Dehydrated mashed potatoes—a review. U. S. Dept. Agr. Western Regional Research Laboratory. Albany, Calif. *AIC-297.*

OLSON, R. L., and HARRINGTON, W. O. 1955A. Potato granules. Development and technology of manufacture. Adv. Food Res. *6.*

OLSON, R. L., and HARRINGTON, W. O. 1955B. The technology of potato granule manufacture. Am. Potato J. *32,* 106–111.

OLSON, R. L., HARRINGTON, W. O., NEEL, G. H., COLE, M. W., and MULLINS,

1950. Measurement of non-
ing storage. Food Technol. *4*,

51. Factors affecting storage
rn Regional Research Labora-

iA. Non-enzymatic browning
s of sulfite level and method of

W. O. 1955B. Rates of non-
ion. Food Technol. *9*, 433–438.
food materials. Application of
nal. Ed. *17*, 312–316.
es. Proc. Potato Utiliz. Conf. *8*,

How to unit-engineer a line

, R. M., HENDEL, C. E., and
for potato granules. Food Tech-

., and BRYAN, L. A. 1947.
e. Ind. Eng. Chem. *39*, 1294–

l POOL, M. F. 1951. Brown-
ge. Food Technol. *5*, 417–423.
, A. L. 1962. Textural qual-
ing texture. Food Technol. *16*,

1946. Moisture determination
Ind. Eng. Chem. *38*, 725–731.
OORAIKUL, B. 1978. Ultra-
ule process as viewed by SEM.

, WOOD, E. R., and NUTTING,
o granules and its relation to
. *9*, 393–395.
NGTON, W. O., and OLSON, R.
to granules. Food Technol. *11*,

L., HARRINGTON, W. O., and
add-back process for production

ehydrated mashed potatoes—a
rch Laboratory. Albany, Calif.

ato granules. Development and

ne technology of potato granule

COLE, M. W., and MULLINS,

W. R. 1953. Recent advances in potato granule technology. Food Technol. *7*, 177–181.

OORAIKUL, B. 1978. Some characteristics of the freeze-thaw process for potato granule production. Am. Potato J. *55*, 171–181.

POTTER, A. L., JR. 1954. Changes in physical properties of starch in potato granules during processing. J. Agr. Food Chem. *2*, 516–519.

POTTER, A. L., JR., MEEL, E. M., REEVE, R. M., and HENDEL, C. E. 1959. Change in the physical condition of starch of the potato during precooking heating. Am. Potato J. *36*, 444–449.

POTTER, E. F., and HENDEL, C. E. 1951. Determination of sulfite in dehydrated vegetables by direct titration. Food Technol. *5*, 473–475.

PROCTOR, B. E., and SLUDER, J. C. 1944. Dehydration of pre-cooked white potatoes in granular form. Research Reports on Quartermaster Contract Projects, Massachusetts Institute of Technology, July 1, 1943 to June 30, 1944, pp. 227–243.

REEVE, R. M. 1954A. Histological survey of conditions influencing texture in potatoes. I. Effects of heat treatments on structure. Food Res. *19*, 323–332.

REEVE, R. M. 1954B. Histological survey of conditions influencing texture in potatoes. II. Observations on starch in treated cells. Food Res. *19*, 333–339.

REEVE, R. M. 1963. Estimation of extra-cellular starch of dehydrated potatoes. J. Food Sci. *28*, 198–206.

REEVE, R. M. 1977. Pectin, starch and texture of potatoes; some practical and theoretical implications. J. Texture Stud. *8*(1) 1–17.

REEVE, R. M., and NOTTER, G. K. 1959. An improved microscopic method for counting ruptured cells in dehydrated potato products. Food Technol. *13*, 574–577.

RENDLE, T. 1943. Improvements in and relating to the preparation of cooked starchy vegetables in powder form. Brit. Pat. 566,167.

RENDLE, T. 1945. Preparation of cooked starchy vegetables in powder form. U. S. Pat. 2,381,838.

RIVOCHE, E. J. 1948. Improvements in and relating to the drying of vegetables. Brit. Pat. 601,151.

RIVOCHE, E. J. 1950. Drying of starchy foodstuffs. U. S. Pat. 2,520,891.

ROSS, A. F., HILBORN, M. T., JENNESS, L. C., and BARTLETT, E. M. 1946. Selecting and storing potatoes to avoid darkening. Food Inds. *18*, 1011–1013, 1144, 1146, 1148, 1150, 1152.

SMITH, O. 1957. After-cooking darkening of potatoes. Proc. 8th Potato Util. Conf. pp. 87–98.

STEPHENSON, R. M., SANO, T., and HARRIS, P. R. 1958. Storage characteristics of potato granules. Food Technol. *12*, 622, 624.

THOMPSON, J. B., and TOY, E. 1945. Determination of sulfur dioxide. Improved Monier-Williams method. Ind. Eng. Chem., Anal. Ed. *17*, 612–615.

VOLPERTAS, Z. 1939. Process for reducing vegetables containing starch to a dry powder. Brit. Pat. 525,043.

VOLPERTAS, Z. 1944. Art of dried starch bearing food. U. S. Pat. 2,352,670.

WILLIAMS, K. T., and POTTER, E. F. 1953. Report on sugars in plants. J. Assoc. Off. Agr. Chem. *36*, 401–404.

WOOD, E. R., OLSON, R. L., and NUTTING, M. D. 1955. A method for the comparison of consistency in potato granule samples appraised at different times. Food Technol. *9*, 164–168.

ZAEHRINGER, M. V., and LE TOURNEAU, D. 1962. Textural quality of potatoes. I. Comparison of three organoleptic methods. Food Technol. *16*, 131–134.

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